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INV.: Reinhold HAGEL
Stephan KRELL
Peter SCHIMMELPFENNIG
Mehmet TUNA

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I, Gabriele Fuchs, residing at Amrumer Str. 7, 90425 Nuremberg, Federal Republic of Germany, hereby declare that I am conversant with the English and German languages and that I am a competent translator thereof. I declare further that, to the best of my knowledge and belief, the foregoing is a true, faithful, complete and accurate translation of PCT International Application PCT/DE2003/001983 as filed on June 14, 2003 in the name of Conti Temic microelectronic GmbH, the original of which application has been submitted to me in the German language.

Nuremberg, January 12, 2005

Gabriele Fuchs

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Description

Control of the operating mode of an internal combustion engine

The invention relates to a control method for controlling the operating mode of an internal combustion engine as well as a device for controlling the operating mode of an IC engine of a motor vehicle by means of said method.

In particular, the invention relates to a method for detecting and controlling the uneven running of an IC engine. A control device embodying a method of this type, which typically exists with modern vehicles, is e.g. also known as Engine Smoothness Control (ESC). Many cases of engine smoothness control systems of this type are known, so that the design and functionality of the different, known engine smoothness control systems is not explained in detail hereinafter.

Based on the unavoidable existence of process tolerances of the injection system as well as by the occurring ageing effects different fuel quantities are proportioned to the cylinders. Even minor differences of the fuel quantities supplied to the cylinders result in torque variations, what may be the cause of unwanted vibrations for examples of mirrors, steering wheels and the like. Such vibrations have a particular unwanted influence in case of the IC engine of the motor vehicle, as here the engines are often rocked, which must be taken into consideration when dimensioning the engine construction, as this may possibly have a negative impact on the life time of the engine. Moreover, by the said dispersion of the injected fuel quantity an unfavorable impact on noise, life time and emissions of the IC engine is exerted. It is understandably essential to avoid these unwanted impacts.

The said torque variations are reflected for instance in the instantaneous crankshaft speed and in the instantaneous crankshaft acceleration, resp. They can be measured and analyzed in the engine control device.

Starting from here it is the object of the present invention to avoid or at least diminish to the greatest possible extent the torque changes or variations at a uniform crankshaft speed.

This object is attained in accordance with the invention by a method with the features of claim 1, a control device with the features of claim 19 and an IC engine with the features of claim 23.

Accordingly, it is provided:

A control method for controlling the operating mode of an IC engine, in which a control device comprises a device for sampling signals, a downstream arranged device for frequency analysis and a downstream arranged device for cylinder classification, in which at first a speed signal is detected and subsequently the speed signal is transformed into an angle-frequency-range, the transformation being effected by means of a Hartley-transformation (patent claim 1).

A device for controlling the operating mode of an IC engine of a motor vehicle with a device for sampling signals, with a device for frequency analysis being arranged downstream to the device for sampling signals and with a device for cylinder classification being arranged downstream to the device for frequency analysis (patent claim 14).

An IC engine in a motor vehicle with at least one cylinder and with at least one engine control, at least one engine control comprising a device for controlling the operating mode of an IC engine of a motor vehicle (patent claim 23).

The method according to the invention is able to detect the uneven running starting from a detected speed signal and to diminish it by adequate adjusting of the injected fuel quantities. This adjustment is effected in accordance with the invention by a control system, which recognizes which cylinder(s) is/are to be adjusted. Advantageously, the control system provides also an information, which discloses apart from the qualitative information also a quantitative information on the extent of the adjustment, i.e. which cylinder is to be adjusted to what extent.

For this purpose the speed signal is transformed into an angle-frequency-range.

The spectral portions obtained in this way are also called orders. Advantageously, the transformation is effected with the aid of the Hartley-transformation. As the adjustment of single cylinders, in particular, has an impact on the low-frequent spectral portions, primarily these low-frequent spectral portions diminish the uneven running. To adjust the uneven running to zero, a solution may be to primarily correct these low-frequent spectral portions to zero. For this purpose a controller is assigned to the IC engine, which drastically reduces the disturbing spectral portions in the entire operating range and thus clearly improves the vibration behavior of the entire drive chain.

The invention further relates to a method for detecting misfires of an IC engine. A device of this type is usually known as Misfire Detection.

The invention further relates to a method for detecting and controlling the released mean torque and the mean power, resp., of an IC engine.

Advantages and further embodiments of the invention idea will become apparent from the further subclaims taken in conjunction with the drawing and the description.

Fig: 1 shows a block diagram of a control device according to the invention for an IC engine, on the basis of which the method according to the invention is shown;

Fig. 2 shows a detailed block diagram, which demonstrates the block of the cylinder classification.

Like reference numerals refer to like elements or elements with identical functions throughout all views, unless otherwise mentioned.

Figs. 1 shows the block diagram of a control device according to the invention for an IC engine, with the aid of which the method according to the invention is described.

In Fig. 1 a self-igniting IC engine in a vehicle is shown under reference numeral 1

and the control device according to the invention for controlling the cylinder adjustment of the IC engine is shown under reference numeral 2.

The control device 2 comprises a device for sampling signals 3, which detects a rotation of the crankshaft and which generates a signal derived from it. This typically digital signal is supplied to a downstream arranged device 4, which starting from the signal supplied by the device for sampling signals 3 averages an arithmetic mean value. Subsequently, this information is delivered to a device for frequency analysis 5, which performs a spectral analysis. This spectral analysis is then further processed in a correction device 6, which corrects the frequency portions. With the data or information obtained in this way a cylinder classification is performed in a device 7 which is described in detail hereinafter. At the output of the device 7 a classification signal can be tapped, which can be supplied to a downstream controller 8. The controller 8 generates from it a control signal, which can be injected into the IC engine so that the cylinders can be adapted optimally to the given conditions in accordance with the requirements.

Though in Fig. 1 devices 4, 6 have been shown, it must be pointed out that one could do also without one or both of these elements, without considerably affecting the functionality of the control device according to the invention.

Further the present invention is not be restricted to self-igniting IC engines, but can principally also advantageously be used with however embodied IC engines 1.

Fig. 2 shows a detailed block diagram for illustrating the device 7 for cylinder classification. The device 7 contains in a first segment a means for reference phase generation 71, to which means for reference phase calibration 72 and reference phase selection 73 are downstream arranged. In a second segment a device 74 is provided, for which e.g. assessment criteria are determined or calculated, which are accessible later on. Based hereupon the main causers and/or the secondary causers of a disturbance or a deviation are determined. In addition or as an alternative, a possible adjustment for correcting the disturbance and deviation, resp., can be derived already at this moment. In the downstream

unit 76 the qualitative and, if necessary, also the quantitative degrees of adjustment can be determined.

The functionality of the present invention is described in detail with the aid of Figs. 1 and 2 as follows:

The method according to the invention is primarily based on the analysis of the engine speed. For this e.g. a transmitter wheel with preferably equidistant angle markings is arranged at the crankshaft. The time periods between the individual markings of the rotating transmitter wheel are detected by a sensor, for instance an inductive or an optical sensor. Subsequently, the signal detected in this way is converted into revolution speeds in a program-controlled unit, for instance a microcontroller, microprocessor or the like. This program-controlled unit can be a component of the control device 2 according to the invention or can also be contained in the engine control. Conversely, also the control device 2 according to the invention can be a component of the engine control.

Thus in equidistant angle distances sampling values of the crankshaft speed are available. The number of the angle markings is to be chosen to be high enough that the sampling theorem can be complied with.

In case of a quasi-stationary operating state the arithmetic mean value is averaged starting from at least two successive speed segments of the length 720° of the crankshaft. The speed segments of the length 720° of the crankshaft are also called working cycle. Averaging the arithmetic mean value serves to eliminate cyclical variations which result from an uneven combustion. In addition or as an alternative, the arithmetic averaging could be performed also in the angle-frequency range. For this said frequency transformation must be applied to each individual analyzable working cycle. In a further embodiment one could do also without the device 4 for arithmetic averaging, although the invention with a device for arithmetic averaging shows better functionality. The device 4 for arithmetic averaging could also be arranged at another place in the control device 2.

In the ensuing method step the averaged speed signal (cycle duration 720° of the

crankshaft) is subject to a spectral analysis. For the transformation a Discrete Hartley-Transformation (DHT) is performed in accordance with the invention. The said DHT-Transformation, which stems from image processing, unlike the Fourier Transformation which is usually used and widely spread in digital signal processing and telecommunications offers the particular advantage that it can be calculated by exclusively real operations. Here, the speed signal is separated into individual angle-frequencies, also called orders, which serve for assessing the uneven running. Here, the vibrations show a frequency, which is smaller than double the engine speed. As the adjustment of individual cylinders mainly affects the amplitudes of the low-frequent vibrations, in case of a 4-cylinder engine the amplitudes of the 0.5th and of the first order represent the actual values for uneven running. Said orders, hereinafter referred to as relevant orders, can be affected by the injection and designate vibrations with the frequency of half and simple engine speed, respectively. These are clearly diminished by means of the method according to the invention. In this connection the value zero represents the nominal value for the amplitude of the 0.5th and of the first order. Complex numerical values can be derived from the spectral transformation applied to the speed signal, which values can be converted for the respective orders into quantity (or amplitude) and phase.

At this place is must be noted that in case of a 6-cylinder engine in addition the 1.5th order, in case of an 8-cylinder engine in addition the 1.5th and the second order would have to be taken into account.

As the calculated complex numerical values and amplitude- and phase values, resp., are generally tampered due to typically appearing parasitic effects (transmitter wheel errors, moments of inertia, etc.), these are eliminated with the aid of an advantageously provided, so-called towed correction. For this in the stationary towed operation, i.e. in the operating state without injection, measurements are performed for instance of the instantaneous crankshaft speed. The subsequent application of the Hartley-Transformation delivers speed-dependent correction values for the vibrations of the 0.5th and of the first order. These correction values are stored in the control device.

One can do also without this device 6 for correcting the frequency portions,

although the control device 2 according to the invention would show better functionality with this device. Moreover, this correction device 6 could perform also another correction than the towed correction.

The adjusted cylinders are detected with the aid of speed and load dependent reference phases, which are stored in the control device for the relevant orders. Subsequent to the determination of the reference phases, which may be effected at the dynamometer or in the driving mode, these are equally subject to a towed correction. In addition, from the combination of the relevant orders of the reference phases a calibration factor can be derived.

The corrected engine orders represent the basis for the next method step. If the amplitudes of the vibrations of the 0.5th and of first order exceed a given threshold value and if a quasi-stationary operating state is on hand, the control is activated.

Reference phases are assigned to the measured phases of the 0.5th and of the first order. The reference phase of the 0.5th order, which is adjacent to the measured phase, is referred to as the primary phase, the related cylinder as the primary cylinder. The reference phase of the 0.5th order, which is the second next to the measured phase is referred to as the secondary phase and the related cylinder as the secondary cylinder.

By means of the reference phases assigned to the measured phases and the measured amplitudes and phases assessment criteria are established while taking into account the respective load and speed situation, with the aid of which criteria the cylinders to be adjusted and their necessary direction of adjustment are determined. In the present case four assessment criteria are determined, which are referred to hereinafter as PK1-value, PK2-value, PK3-value, AK-value.

By means of the primary phase, the reference phase of the first order and a calibration factor a so-called PK1-value is calculated, which is compared with a given threshold. Equally, a so-called PK2-value is calculated from the primary phase, the secondary phase, the measured amplitude and the measured phase of the 0.5th order, which value is compared with a further given threshold.

Dependent from an exceeding of said thresholds the logic values "HIGH" and "LOW" are associated to the PK1- and PK2-values. Optionally, PK2 can also be determined from the measured phase and the primary phase, i.e. from the distance of both phases.

As a further criterion the so-called AK-value is required. For determining the AK-value the load and speed dependent ratio of the measured amplitudes of the 0.5th and of the first order are compared with a threshold. The comparison with a further threshold value delivers the logic value "HIGH" and "LOW", resp., for the AK-value. In addition or as an alternative, also a so-called PK3-value, which is determined by means of the primary phase, a complementary primary phase (= phase of the cylinder not adjacent to the primary cylinder), the measured amplitude and the measured phase, can be compared with a further threshold, thus resulting for the PK3-value the logic value "HIGH" or "LOW".

In a further method step, the respective cylinder to be adjusted and if necessary also the respective necessary adjustment device are determined.

The PK1-value is used for determining the relevant adjusted cylinder, for instance the main causer of the adjustment, and its direction of adjustment. If for instance PK1="HIGH", the main causer of the adjustment is the cylinder related to the primary phase. Moreover, the identified cylinder is too greasy, i.e. a too large fuel quantity is supplied to the cylinder. In this case the injected fuel quantity of this cylinder should be reduced.

The values PK1 and PK2 combined with the AK-value - optionally also with the PK3-value - reveal the cylinder with the second highest portion of the adjustment (=secondary causer) as well as its direction of adjustment.

The contribution of adjustment of the secondary causer is typically determined relatively to the main causer. The relative contribution of the secondary causer can be determined in analytic manner. As an alternative, the secondary causer can be suppressed. In this case typically merely a single cylinder, namely the main causer, is adjusted.

The measured relevant orders are advantageously compensated or at least diminished to the greatest possible extent by generating the adequate counter vibrations. For this purpose the determined qualitative adjustments of the main causer and/or the secondary causers are distributed to all cylinders such that the sum of the adjustments over all 4 cylinders equals or nearly equals zero. By means of this the original engine torque and the original engine power, resp. are not changed.

The amplitudes of the relevant orders represent the offset and are subject to speed and load dependent weighting. Finally, with the aid of the determined qualitative adjustments and the actual amplitudes of the relevant orders individual, quantitative correction factors are determined. These are supplied to a controller 8, which in the case that there is no controller restriction affects the individual injected fuel quantities necessary for the respective cylinders. In the present example of embodiment the controller 8 is a simple I-controller. However, it goes without saying that also any control device could be used here, which dependent from the determined correction values provides a control signal at the side of the output.

Apart from the now described functionality the control device according to the invention comprises advantageously also additional functionalities. The functionalities of the controlling device according to the invention described hereinafter can be implemented additionally or as an alternative to the above described control of the uneven running of an IC engine (ESC-control).

Misfire Detection

Due to the occurrence of misfires that are unavoidable with an IC engine unwanted, non-burned fuel can be released into the environment. Moreover, this may result in a permanent damage of exhaust gas treatment systems existing in modern vehicles, for example of the catalytic converter. Both implicate that the vehicle exhaust pollution of the environment is increased. To avoid this to the greatest possible extent there are national and international regulations and laws (e.g. OBD II, E--OBD), which prescribe inter alia a device for recognizing misfires in motor vehicles.

The occurrence of misfires leads to torque variations, which reflect for example in the instantaneous crankshaft speed and in the instantaneous crankshaft acceleration, resp. By means of the method according to the invention described hereinafter it is possible to detect misfires starting from a speed signal. Further it is possible to recognize which cylinder has misfires. For this the speed signal is transformed into the angle-frequency range in an appropriate manner as in the engine smoothness control. As the adjustment of individual cylinders mainly impacts the low-frequent spectral portions, these are primarily used for detecting misfires.

The method according to the invention in turn is based on the analysis of the engine speed. For this purpose e.g. a transmitter wheel with preferably equidistant angle markings is arranged at the crankshaft. The periods between the individual markings of the rotating transmitter wheel are detected by a sensor and are subsequently converted in the microcontroller into speeds.

By means of this the sampling values of the crankshaft speed are determined in equidistant angle distances. Here it must be ensured that the number of angle markings is high enough so that the sampling theorem can be complied with in any case.

In case of a quasi-stationary operating state a 720° long section of the speed signal, which may also be referred to as working cycle, is subject to a spectral analysis by means of a Discrete Hartley-Transformation (DHT). The speed signal is separated into individual angle-frequencies, which serve for detecting misfires. As the adjustment of individual cylinders mainly affects the amplitudes of the vibrations, which have a frequency smaller than double the engine speed, with a 4-cylinder engine the amplitudes of the 0.5th and of first order represent sizes from which conclusions can be drawn to the existence of misfires. The said orders, hereinafter referred to as relevant orders, designate vibrations with the frequency of half and simple engine speed, respectively. At this place is must be noted that in case of a 6-cylinder engine in addition the 1.5th order, in case of an 8-cylinder engine in addition the 1.5th and the second order would have to be taken into account. In general, the spectral transformation applied to the speed

signal delivers complex numerical values, which can be converted for the respective orders into quantity and amplitude and phase, resp.

As the calculated complex numerical values and amplitude- and phase values, resp., are generally tampered due to always appearing parasitic effects - for instance a transmitter wheel error, an error of the moment of inertia, etc. - these are eliminated with the aid of a so-called towed correction. For this purpose in the stationary towed operation (=operating state without injection) measurements are performed for instance of the instantaneous crankshaft speed. The subsequent application of the Hartley-Transformation delivers advantageously speed-dependent correction values for the vibrations of the 0.5th and of the first order. These correction values are stored in the control device.

The occurrence of one or more simultaneously appearing misfires leads the amplitudes of the relevant orders to increase strongly. By analyzing the amplitudes the occurrence of a misfire can be displayed. The comparison of the amplitudes with a given threshold is performed in a so-called amplitude discriminator. It states the existence of misfires for each working cycle.

If for example the amplitudes of the 0.5th and of the first orders lie below the said threshold, there is no misfire. If both exceed them, it is recognized that either one cylinder or three cylinders have a misfire. Two misfires of adjacent cylinders are recognized if only the amplitude of the 0.5th order exceeds the threshold. Two misfires of complementary, i.e. cylinders that are not adjacent in the firing order, are on hand if only the amplitude of the first order exceeds the threshold.

The determination of the cylinders, which have misfires, is effected in the block cylinder detection with the aid of speed and load dependent reference phases, which are stored for the relevant orders in the control device. Subsequent to the determination of the reference phases, which may be effected at the dynamometer or in the driving mode, these are equally subject to a towed correction. In addition, from the combination of the relevant orders of the reference phases a calibration factor can be derived. Reference phases are assigned to the measured phases of the 0.5th and of the first order. The reference phase of the 0.5th order and the related cylinder, resp., which is

closest to the measured phase of the 0.5th order, delivers the so-called primary cylinder.

By means of the reference phases and the calibration factor a reference phase criteria is determined. By taking into account the respective threshold exceedings in the amplitude discriminator and the knowledge of the primary cylinder the misfiring cylinders are identified.

Torque tracing - Performance tracing

Due to the unavoidable occurrence of ageing effects of the engine and above all of its injection system the engine torque released by the IC engine and the released engine power, resp., diminish over the years. This effect is considered as a deficiency in particular with commercial vehicles, as they demand much higher engine running times as required with passenger cars. Exchanging the engine is too expensive on the one hand and on the other hand the commercial vehicle also will fail for a longer period of time. In particular, the occurrence of manufacturing tolerances causes a more or less strong variation in the engine torque and as a consequence thereof a dropping of the engine power, which can often only be compensated by time-consuming strip end compensation.

By arranging torque sensors or cylinder pressure sensors in the cylinders the engine torque and the engine power, resp., can in fact be determined, however, this requires additional structural expenditure. Variations in the released engine torque and in the released engine power, resp., reflect for instance in the instantaneous crankshaft speed and instantaneous crankshaft acceleration, resp. These can be analyzed in the engine control device while using an already existing sensor.

By means of the method according to the invention hereinafter described, it is possible to detect the released engine torque and the released engine power, resp., starting from the speed signal as well as to affect or correct this by an appropriate adjustment of the injected fuel quantities.

As the combustion energy is substantially contained in marked frequency

portions of the speed signal, it is transformed into the angle-frequency range. The resulting spectral portions are also referred to as orders. By analyzing the amplitude of the vibration of the second order in case of a 4-cylinder engine conclusions can be drawn to the released engine torque and the released engine power, resp. As an alternative, also the 4th, 6th, 8th, etc. orders can be used for this. Accordingly, for instance with a 6-cylinder engine the amplitude of the vibration of the 3rd order and with an 8-cylinder engine the amplitude of the vibration of the 4th order and the even-numbered multiples of the said orders, resp., are analyzed.

After an adequate calibration the said spectral portions represent actual quantities for the released engine torque and the released engine power, resp., and can be compared with the engine torque and the respective engine power, resp., demanded by the engine control device. A controller is assigned to the IC engine, which minimizes the difference between actual engine torque and nominal engine torque by varying the injected fuel quantity.

The method according to the invention is based on the analysis of the engine speed just as in the above described methods. Here, in turn a transmitter wheel arranged at the crankshaft is provided with preferably equidistant angle-markings. The periods of time, which occur with a rotating transmitter wheel between the individual markings of the rotating transmitter wheel are detected by a sensor and converted by a microcontroller into speeds assigned to these periods. Thus, in equidistant angle distances sampling values of the crankshaft speed are available. Also in this case it is to be ensured that the sampling theorem is always complied with.

In case of a quasi-stationary operating state the arithmetic mean value is averaged starting from at least two successive speed segments of the length 720° of the crankshaft. This serves to eliminate cyclical variations which result from an uneven combustion.

In the ensuing method step the averaged speed signal (cycle duration 720° crankshaft) is subject to a spectral analysis by means of a Discrete Hartley-Transformation (DHT). Here, the speed signal is separated into individual angle-

frequencies, wherein in the method according to the invention the torque information is generated from the amplitude of the vibration of the second order (=vibrations with the frequency of the engine speed). Complex numerical values are generally provided by the spectral transformation applied to the speed signal, which values can be converted into quantity and amplitude, resp., and phase.

As the calculated complex numerical values and amplitude- and phase values, resp., are generally tampered due to typically appearing parasitic effects (e.g. transmitter wheel errors, moments of inertia, etc.), these are eliminated with the aid of a correction device (i.e. towed correction). For this in the stationary towed operation (=operating state without injection) measurements are performed for instance of the instantaneous crankshaft speed. The subsequent application of the Hartley-Transformation delivers speed-dependent correction values for the vibration of the second order. These correction values are stored in the control device.

As the amplitude of the second order, which is a measurement for the released engine torque and the released engine power, resp., increases with a fixed speed strictly monotonously with the load, it can be detected in case of a reference engine and can be stored independent from the speed in a family of characteristics. This family of characteristics then serves as a reference for detecting the actual engine torque and the actual engine power, resp.

In addition or as an alternative, the calculation of the actual engine torque and of the actual engine power, resp., can be performed in an analytic manner.

The difference between the nominal engine torque requested by the engine control device and the de facto actual engine torque is detected by an ensuing control system and is minimized by varying the injected fuel quantity. Before processing the introduced method the speed strokes can also be equated by means of a so-called engine smoothness control (ESC).

The above examples of embodiment have been depicted by way of an IC engine with four cylinders. However, the invention is not to be restricted to exclusively IC engines of this type, but can, of course, also be extended to IC engines with

more or less than four cylinders in case of adequate adaptations that are obvious to the expert.

The above examples of embodiment describe the invention by way of a Hartley-Transformation. However, in case of an adequate modification the invention can also very advantageously been used with the aid of another transformation, e.g. a Fast Fourier Transformation (FFT), a Discrete Fourier Transformation (DFT) or the like, although the invention is most advantageous and thus most suitable in the case of a Hartley-Transformation.

In the above examples of embodiment the arithmetic mean value was averaged respectively. However, the invention is not be restricted exclusively on this, but can also very advantageously be used in case of a geometrical averaging of the mean value or the like.

Recapitulating, it can be ascertained that by the above described control system with the aid of the Hartley-Transformation a control of the operating mode of the IC engine is realizable in a very elegant and nevertheless very simple manner while completely renouncing of solutions known so far.

The present invention has been demonstrated with the aid of the above description to best possible explain the principle of the invention and its practical application, however, the invention can, of course, be realized with an adequate modification in diverse other forms of embodiment.

List of reference numerals

1	IC engine in a motor vehicle
2	Control system
3	Device for sampling signals
4	Device for averaging the arithmetic mean value
5	Device for frequency analysis
6	Correction device for correcting the frequency portions
7	Device for cylinder classification
71	Means for reference phase generation
72	Means for reference phase calibration
73	Means for reference phase selection
74	Device with given assessment criteria
75	Unit for determining main causers and/or secondary causers of a disturbance or a deviation
76	Unit for determining the qualitative and/or quantitative adjustment measures
8	(I-) Controller